IDENTIFYING THE SEX PHEROMONE OF THE SUGARCANE BORER MOTH

Economic impact of ACIAR project CS2/1991/680

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Foreword

ACIAR's impact assessment reports provide information on project impacts which helps to guide future research and development activities. While the main focus of these commissioned reports is on measuring the dollar returns to agricultural research, emphasis is also given to analysing the impacts of projects on poverty reduction.

The project evaluated in this report was a small project that helped to identify the sex pheromone (attractant chemical) of the sugarcane borer, *Sesamia grisescens*. This insect is a very serious pest of sugarcane in Papua New Guinea, and is also regarded by Australian quarantine authorities as the most serious insect pest threatening the sugar industry here. Papua New Guinea regularly applies insecticide sprays to control the borer, and has previously used a labour-intensive and destructive sampling system to determine numbers of borer larvae (to know when spraying is needed). Now they use the pheromone, which has become an important tool in the pest monitoring system. Pheromone trap catches are used as the basis for timing insecticide applications, and are much faster, simpler and cheaper.

The availability of the pheromone will also be of great use to Australia should the borer ever enter here. It will enable detection and monitoring for eradication or make control much simpler than it would otherwise have been.

This report is Number 34 in ACIAR's Impact Assessment Series and is also available for free download at <www.aciar.gov.au>.

Peter Core
Director
Australian Centre for International Agricultural Research

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Acknowledgments

I thank Dr Lastus Kuniata of Ramu Sugar for his superb assistance in undertaking this evaluation. Dr Kuniata first suggested the project for evaluation and subsequently put together an information pack about borer and its impact on cane and sugar production at Ramu. The evaluation would not have been possible without his work. I am grateful to David Raitzer (FAO) and Richard Vickers (CSIRO) for comments on an initial draft.

As always, I also thank Dr Deborah Templeton, formerly with ACIAR and now with the International Rice Research Institute, for facilitating the evaluation.

Details of project evaluated

ACIAR project CS2/1991/680	Identification of the sex pheromone of the noctuid cane borer *Sesamia grisescens*
Collaborating organisations	CSIRO Division of Entomology (CE), Canberra, Australia; Ramu Sugar Limited (RSL), Lae, Papua New Guinea
Project leaders	Dr C P Whittle (CE); Dr Lastus S Kuniata (RSL)
Duration of project	1 July 1991 – 31 August 1993
Total ACIAR funding	A$16,000
Project objectives	To determine the chemical composition of the sex pheromone of the noctuid cane borer *Sesamia grisescens*, from which it was hoped a synthetic hormone could be created as a lure, to monitor traps or to disrupt mating patterns, to aid in their control in PNG.
Location of project activities	Ramu Valley, Lae, PNG; Canberra, Australia

Summary

- The cane borer *Sesamia grisescens*, a species of noctuid moth, is a major pest of sugarcane in Papua New Guinea (PNG), and has caused major crop losses in the past.
- Ramu Sugar, PNG's commercial sugar producer, has developed an integrated pest management strategy (IPM) to deal with the problem.
- While apparently reducing the level of attack, the strategy was unable to achieve a high level of control of the borer.
- A major addition to the IPM strategy was the introduction of sex-pheromone-baited traps to capture moths in flight and use information on moth numbers to schedule spraying.
- The use of these traps has proved extremely effective in recent years, leading to almost complete control of the moths and eliminating crop losses.
- The research that led to the identification of the pheromone for use in the traps was partially funded by ACIAR project CS2/1991/680. In this evaluation we estimated the net benefits of this research.
- We find that the present value of net benefits of the research are significant, ranging from between $4 million and $25 million over a 30-year time frame.
- With the modest costs of the overall research, this implies a benefit–cost ratio of between 46:1 and 266:1.
- This extremely high return builds on the excellent research undertaken at Ramu to determine the dynamics and nature of the costs from the cane borer.

1 Introduction

Papua New Guinea (PNG) — believed to be the home of domesticated sugarcane — is also the home of major pests to the same plant, providing a constant challenge to efficient and cost-effective commercial production at Ramu Sugar's 8500 ha sugar estate in the Ramu Valley.

Since its beginnings, Ramu Sugar has had to develop a series of tools for dealing with pests of various kinds, and has in some years struggled to achieve break-even yields. One of the latest battles has been with a cane-boring noctuid moth, *Sesamia grisescens,* which posed major challenges to production through the mid 1980s and early 1990s.

During this period, Ramu Sugar developed an integrated pest management (IPM) scheme to control outbreaks and hence significantly reduce the costs of production. Since 2001, a major tool in the IPM strategy has been the use in traps of the sex pheromone of the cane borer. The sex pheromone is a chemical released by female moths to attract males for mating. The identification of the pheromone was partially funded by ACIAR and is the subject of this impact assessment analysis.

ACIAR funding was modest (around $16,000 in 1991), as was the total cost of the project. Yet, as the following analysis will indicate, the impacts have been significant.

This report is structured as follows. Chapter 2 provides an overview of Ramu Sugar, as well as the pest with which it has had to deal to maintain production. Chapter 3 provides an overall framework for evaluation of the ACIAR-funded research, looking in particular at the economics of disease control in the presence of major import restrictions. Chapter 4 uses this overall framework to conduct a benefit–cost analysis of the research. Chapter 5 sums up the results of the analysis.

2 Ramu Sugar and its cane borer nemesis

Ramu Sugar

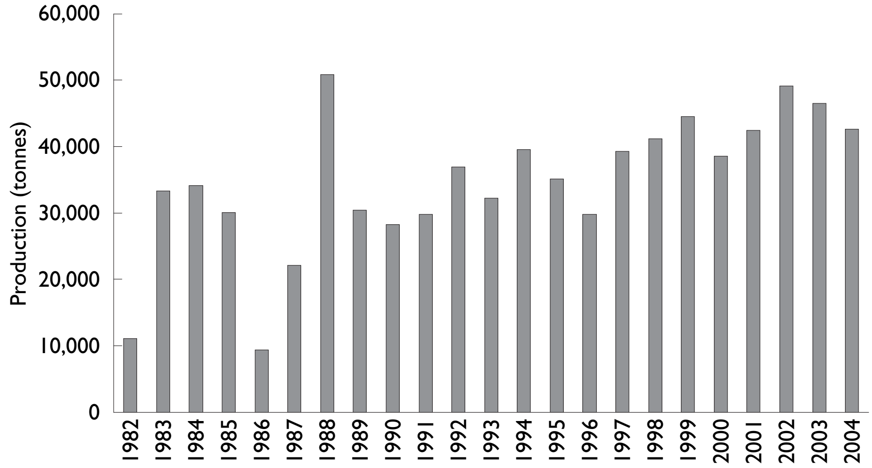
Ramu Sugar, located in the Ramu Valley near Lae, was established in 1979 with around 200 ha under cane, the area expanding rapidly to 5500 ha in the first 6 years of operation. Cane crushing began in 1982 with initial production of around 10,000 tonnes of sugar. Today the estate covers around 8500 ha and produces around 50,000 tonnes of sugar a year, sufficient to satisfy local demand and to allow for some export. Figure 1 shows the history of sugar production and Figure 2 the history of sugar yields.

Around a quarter of total cane production comes from out-growers, under a scheme that was initially set up in 1983, and was modified in 1987 to be run from an out-grower office within Ramu Sugar. There are currently around 150 out-growers, to whom Ramu Sugar provides the resources, extension services and training needed for these locals to develop farming and business skills (Kuniata 2004).

Production at Ramu is protected by a high import tariff. It is expected that this protection will decline over time.

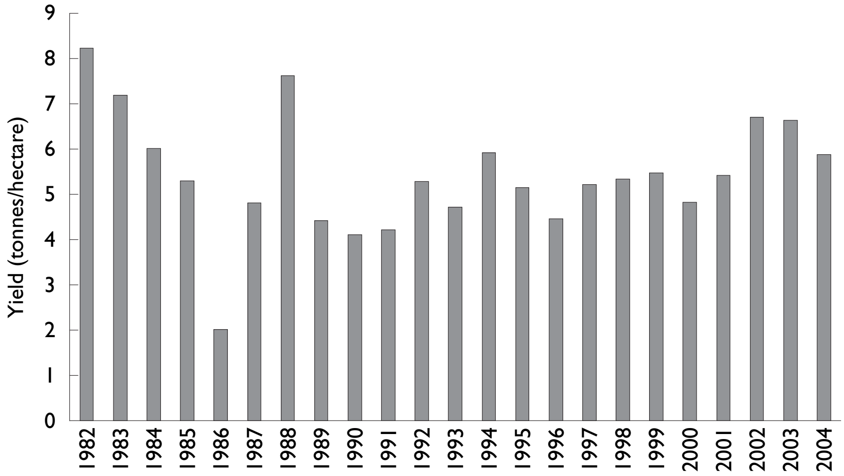
Total costs of production are generally higher than world prices. Ramu is able to export through marginal cost pricing of exports (export prices are lower than domestic prices).

Figure 1. Sugar production by Ramu Sugar, Papua New Guinea, 1982–2004



Data source: L. Kuniata (pers. comm.).

Figure 2. Sugar yields at Ramu Sugar, Papua New Guinea, 1982–2004



Data source: L. Kuniata (pers. comm.).

The cane borer

Sugarcane cultivation at Ramu is plagued by a number of pests and diseases including Ramu stunt,[1] white grubs, downy mildew and ratoon stunting disease.[2]

One of the most important, however, is the noctuid-moth cane borer *Sesamia grisescens* (Lepidoptera: Noctuidae), which is endemic to PNG.[3] First described in 1911, it was in the 1960s recognised as the most important pest of village sugarcane in PNG. Its potential as a pest was suggested in 1982 and realised in 1987 with an 18% crop loss at Ramu.

The adult female cane borer lays her eggs beneath the sheath of younger leaves in the sugarcane stalk. After hatching, the larvae bore into the stalk and feed, ultimately leading to the death and subsequent rotting of the bored stalk.

The borer is capable of doing significant damage. Figure 3 shows the history of attacks in PNG in terms of the percentage of bored stalks and Figure 4 the estimated losses in terms of reduced cane yield.

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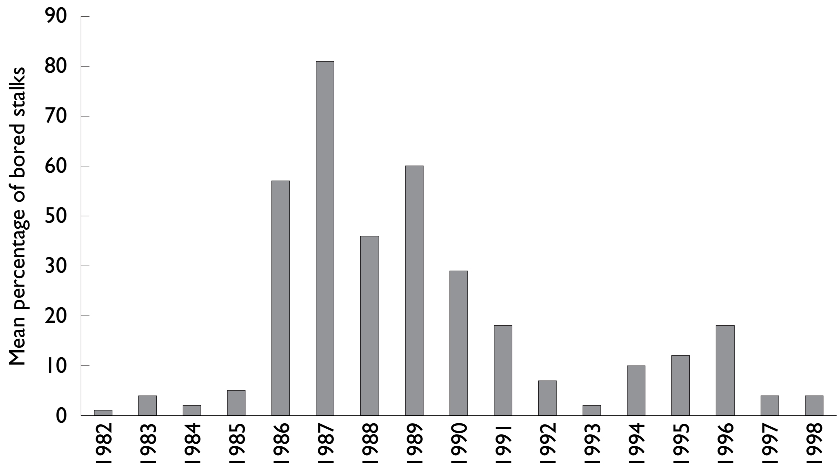
[1] Ramu stunt is a disease, apparently unique to PNG, that was first recognised in 1986 when it caused large production losses at Ramu Sugar. A large percentage of the estate was replanted with a highly resistant variety, which allowed it to escape commercial disaster. A virus, possibly transmitted by a planthopper may cause Ramu stunt, but this has yet to be confirmed.

[2] This disease is caused by a bacterium and is one of the most important pathogens of sugarcane worldwide. Depending on the variety, yield losses can be substantial.

[3] For further detail on the pest see, e.g., <http://www.tpp.uq.edu.au/disease/sesamia.htm>.

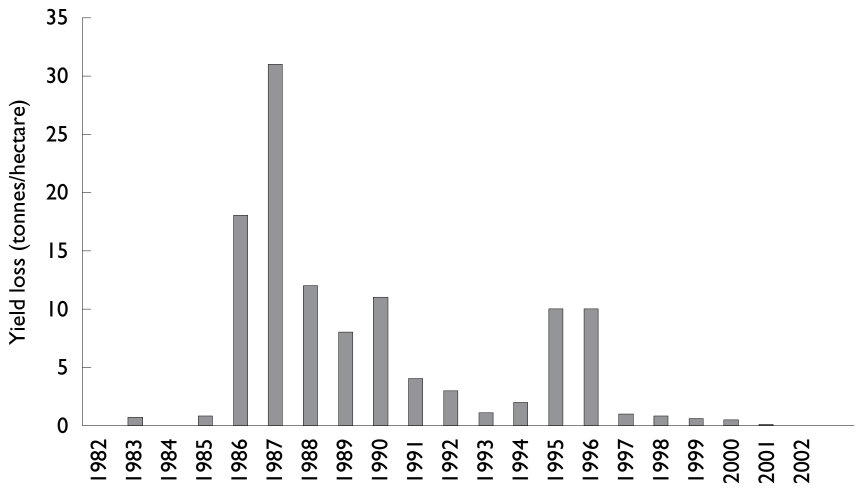
The very high levels of attack in 1986 and 1987 followed the replanting of the estate with the highly susceptible variety 'Cadmus' (the estate was replanted after the Ramu stunt attack). Since then, this variety has mostly been replaced by less-susceptible varieties, although the level of attack has never been reduced to zero.

Figure 3. History of cane-borer attack in Papua New Guinea, 1982–1998



Data sources: Kuniata (1998); Lloyd and Kuniata (2000).

Figure 4. Estimated sugarcane yield losses in Papua New Guinea as a result of cane-borer attack, 1982–2002



Data sources: Kuniata (1998); Lloyd and Kuniata (2000).

The ACIAR-funded project

As part of ongoing pest-control measures, CSIRO and Ramu Sugar established a project to determine the chemical identity of the sex pheromone for the cane borer. The project was jointly funded by ACIAR (which contributed $16,234), CSIRO (contributing $26,958) and Ramu Sugar (contributing $5000).

The project entailed both field trials and laboratory work between July 1991 and August 1993.

The field trials involved moth traps with a number of compounds used as attractants. These were set out in fields of cane of different varieties. The initial compounds were based on known attractants of related species. Careful analysis of the number of moths in each trap was used to assess the efficacy of different compounds.

The laboratory research involved transporting 100 male and 100 female moth pupae to Canberra (under strict quarantine) and using these for both chemical and electrophysical analysis. The chemical analysis used gas chromatography to identify the components of the sex pheromone gland. The electrophysical analysis used male antennae to test responses to various compounds.

The research resulted in the identification of a synthetic attractant for use in moth traps (Whittle et al. 1995).

Adoption of the research findings

Following this research, Ramu Sugar has continued to evaluate the use of pheromone traps, in particular incorporating the use of the traps into its overall IPM scheme.

IPM at Ramu

Control of the cane borer is a complex issue which, as already noted, Ramu Sugar has approached by developing an IPM scheme. Ramu's IPM involves several different instruments including:

- chemical spraying
- biological control
- cultural control.

None of these methods is sufficient alone, and each has different costs and benefits, but overall the strategy has met with some success (Kuniata 2002).

The pheromone in the context of the IPM

The pheromone identified as part of the ACIAR-funded project has been slotted into the overall IPM strategy. In particular, the pheromone-baited moth traps have been used as a very effective method of pest monitoring.

Before the availability of the pheromone trap (from 1986 to 2000), destructive sampling was used to monitor the borer. Stalks were sampled from a block, split open and the various life stages of the borer and damage found recorded. This information was used to direct the release of parasites and/or spraying with chemical. The estimated cost of this method was around US$2/tonne of sugar. As well as being costly, this method was not very effective, as spraying could be scheduled only after damage had been done, and when the borer was largely protected within the cane.

With pheromone traps, the numbers of moths in the traps are used to schedule insecticide spraying. This method is not only cheaper than destructive sampling (around US$0.56/tonne of sugar) but also considerably more effective. The pheromone trap method allows insecticides to be sprayed when the moths are in flight, and before they have mated, so that residues are on the plants when the eggs hatch. As a result, up to 100% mortality has been observed in hatching eggs or young larvae.

The pheromone traps were brought into use at the Ramu estate in October 2000, with the 2001 crop being the first one for which the trap technology was fully in place. The introduction of the pheromone traps for monitoring has greatly improved the efficacy of the insecticides used, with pest numbers and damage becoming insignificant (L. Kuniata, pers. comm.). Since the introduction of the pheromone traps, the amount of insecticide used for borer control has been reduced to around one-sixth of its previous value in terms of weight of active ingredient.

3 Conceptual framework for the economic analysis

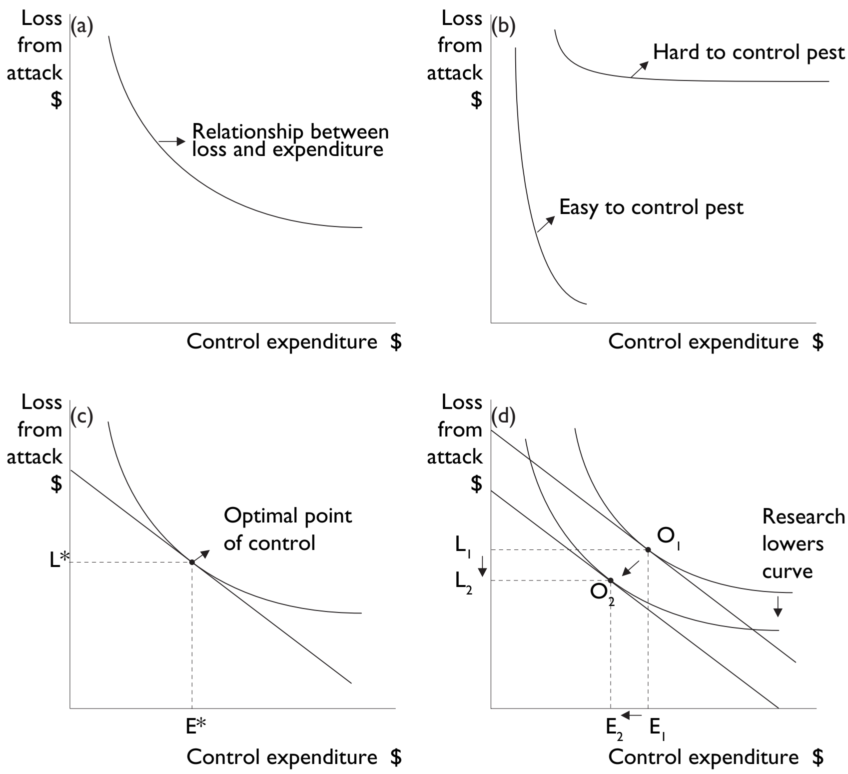
The economics of pest management

Pest management is a balancing act. On the one hand it is important to try to avoid the economic losses from pest attack, while on the other it is important not to spend too much on eliminating the pest, certainly no more than the value of the foregone production.

The broad economics of pest management have been set out in a variety of publications including the 'classic' paper by Mumford and Norton (1984). Sinden et al. (2004) discuss the economics of pest management in an Australian context (for weeds, but the principles are the same as for insects).

A common way of considering the management of pests is to imagine a continuous relationship between the loss from pest attack and the amount spent on control. Such a relationship is illustrated in Figure 5(a). The curved line (a 'loss-expenditure frontier') shows that, as control expenditure increases, the loss from attack declines.

Figure 5. Graphical depiction of some factors in the economics of pest control



The exact shape of this curve will depend on many factors, including the characteristics of the pest and its biology. Figure 5(b) illustrates two possible extremes. The 'hard to control pest' is one where control expenditure has very little effect on reducing the loss from attack. The 'easy to control pest' is one where relatively little expenditure results in a significant reduction in the loss from attack. The cane borer moth at Ramu is a pest that is hard to control.

The trade-off between loss from attack and control expenditure implies that there may be an optimal level of control. Such a level is illustrated in Figure 5(c). The straight line shows the collection of points for which the sum of control expenditure and loss from attack are the same. Where this line is tangential to the loss-expenditure frontier is the point of optimal control. Any control expenditure greater than E^* would lead to a reduction in the loss from attack less than the increase in control expenditure — clearly not a sensible idea. Similarly, any expenditure less than E^* would lead to an unnecessary increase in the loss from attack.

The optimal point of control is related to, but not the same as, the 'economic threshold' idea used in pest-control decision-making. The economic threshold is the density of a pest population that justifies treatment. The density is measured in physical terms, and the economic threshold is used as a practical rule to help decide whether or not to treat the problem (to incur control expenditure).

What is important in considering the impact of research is to examine the way in which the research influences the loss-expenditure frontier. As illustrated in Figure 5(d), successful research into better control methods will shift the frontier downward to the left (towards the origin). This means that, at every point along the frontier, loss from both attack and control expenditures is lower. At the optimal point of control, both the control expenditure and the loss from attack are lower. The value of the reduced control expenditure and the reduced attack is a measure of the value of the research.

Evaluation under uncertainty

One problem in practical pest control, and also in the evaluation of research, is that there are several uncertainties in the pest management system.

First, the level of attack in any given year is uncertain. It will depend on a large variety of factors, including climate, availability of nutrients, previous attacks and so on. To get a true picture of the impact of the pest, it is important to take this uncertainty into account.

Second, the relationship between attack and economic damage is also uncertain. We are fortunate in this evaluation that a large amount of research has taken place at Ramu which identifies the ways and extents in which the pest affects sugar production. It is important to keep in mind, however, that these relationships are statistical, and that there is also an inherent uncertainty in the damage function.

In the analysis presented below, we account for these uncertainties using Monte Carlo simulation[4] of the uncertain parameters. Peterson and Hunt (2003) provide an example of the use of Monte Carlo simulation in practical pest control.

One advantage of using Monte Carlo simulation is that it automatically provides a sensitivity analysis of the evaluation of the research. In effect, the Monte Carlo analysis allows the systematic testing of a large number of alternative assumptions.

Valuation with import protection

An interesting question that arises in the context of Ramu Sugar is how to value the losses from the cane borer (and, concomitantly, the gains from the research). Ramu Sugar is protected by a very high import tariff, allowing the domestic PNG sugar price to be higher than the world price.

Figure 6 explores issues in the gains from research in the presence of an import tariff.

Figure 6(a) shows the typical set up for measuring the welfare benefit of research. Research shifts the supply curve to the right from S to S_1. This results in an increase in both consumer and producer surplus, with the overall economic gain equal to the area *ABCD*. Figure 6(a) of the chart assumes that the shift in the supply curve leads to a reduction in the price, and it is this that generates benefits to consumers.

Figure 6(b) shows the situation with an importable good (and no tariff). In this case, the world price is fixed (changes in local supply do not affect the world price). Before the research, local supply is at *QS*, and local demand at *QD*. The difference is satisfied by imports. With the research, the supply curve shifts from S to S_1. From the consumer's perspective there has been no change, as the price has not changed. The producer, however, has gained by the area *ABCD*, which is the total welfare gain from the research in this case.

Figure 6(c) shows the more-complicated situation with a tariff. As before, the shift in the supply curve does not affect the consumer, who still pays the tariff-inclusive price and who still suffers a welfare loss as a result of

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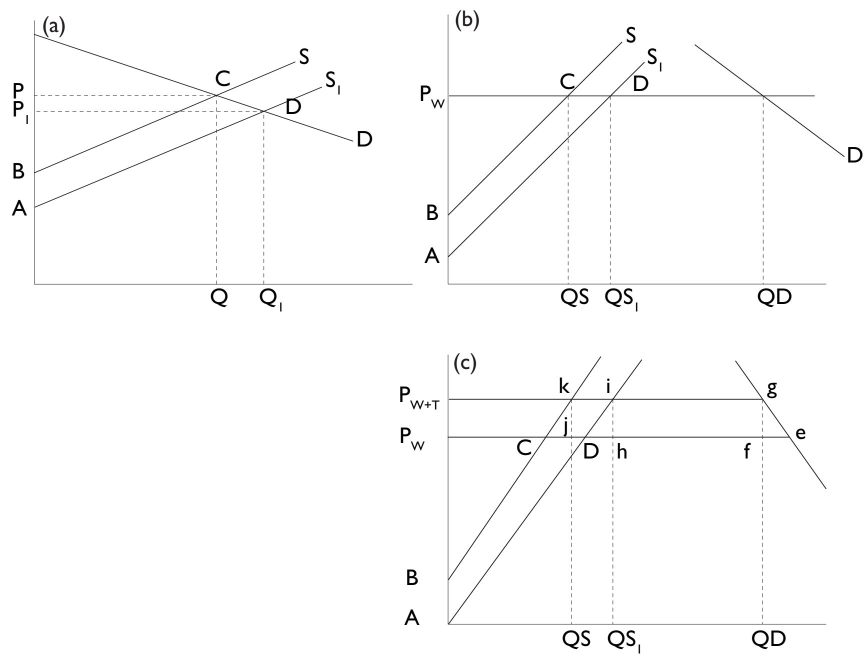
[4] Monte Carlo simulation involves sampling (usually many thousands of times) from the probability distribution of the uncertain parameters and then generating the probability distribution for the calculated result (in this case the value of the research). Monte Carlo simulation was named by the Polish–American mathematician Stanislaw Ulam, apparently in honour of a relative with a penchant for gambling.

the tariff. When the supply curve shifts, the gain in producer welfare is equal to the area *ABki*. However, government revenue is reduced by the amount *jkih*, and so the net increase in community welfare is the area *ABCD*. Thus, the net gain is equal to the area between supply curves *below* the world price line.

Figure 6. Graphical presentation of how research benefits change with trade and tariffs



What this means is that the benefits of the research should be valued at the world price of sugar, not the domestic price. In some ways this result is obvious; it simply says that the opportunity cost to PNG from a tonne of sugar lost as a result of the borer is the price of that tonne on the world market, because PNG always has the option of replacing the loss with imports.

4 Benefit–cost analysis

Borer attack and economic loss

To estimate the value of the benefit of the pheromone traps, we need to generate a baseline estimate of the economic losses that were likely to have occurred as a result of the borer in the absence of the traps. That is, the baseline estimate needs to assume that the only control in place was due to the methods available before the pheromone was developed.

The value of the pheromone traps is the difference between the economic losses without the traps and the economic losses with the traps. This will in turn depend on the level of control that the traps allow.

The economic losses from the borer come about through:

- reduced sugar production (and hence reduced revenue) which is, in turn, a result of
  - reduced cane yield (tonnes of cane per hectare)
  - reduced sugar yield (sugar per unit of cane, also known as sugar 'rendement')
- increased harvesting costs
- monitoring costs.

Estimating the gain from the traps

If π_B is the profit from sugar production *with* the borer (under the baseline) and π_T is the profit from sugar production with the *traps* as an additional control measure, then the value of the traps is equal to π_T less π_B, the amount by which the trap has led to increased profit.

We can write each of these profits as:

$$\pi_B = P \times Q - Loss_B - HC_B - MC_B - OtherCosts \qquad (1)$$

$$\pi_T = P \times Q - Loss_T - HC_T - MC_T - OtherCosts \qquad (2)$$

where

- P is the price of output
- Q is potential production
- $Loss_B$ and $Loss_T$ are the sugar losses with the borer and with the traps (these losses are, in turn, equal to the quantity of loss times the price)
- HC_B and HC_T are harvest costs with the borer and the traps
- MC_B and MC_T are monitoring costs with the borer and the traps
- *OtherCosts* are other production costs.

Here we have assumed that total cane area is the same with the borer and with the traps and that other costs also remain the same. From equations (1) and (2), it is evident that:

$$\pi_T - \pi_B = (Loss_B - Loss_T) + (HC_B - HC_T) + (MC_B - MC_T) \qquad (3)$$

Thus, the benefits from the trap have three components: the reduction in the loss of sugar, the reduction in the harvesting costs and the reduction in monitoring costs.

We use equation (3) to calculate the value of the traps.

Estimating damage from the borer

The probability of attack

The level of attack (measured as the proportion of bored stalks) is clearly a highly uncertain variable. The history of attack at Ramu suggests that the activities of the moth depend on a number of factors including rainfall and the availability of nitrogen. Ideally, moth attack should be simulated using a model of the activities of the moth itself.

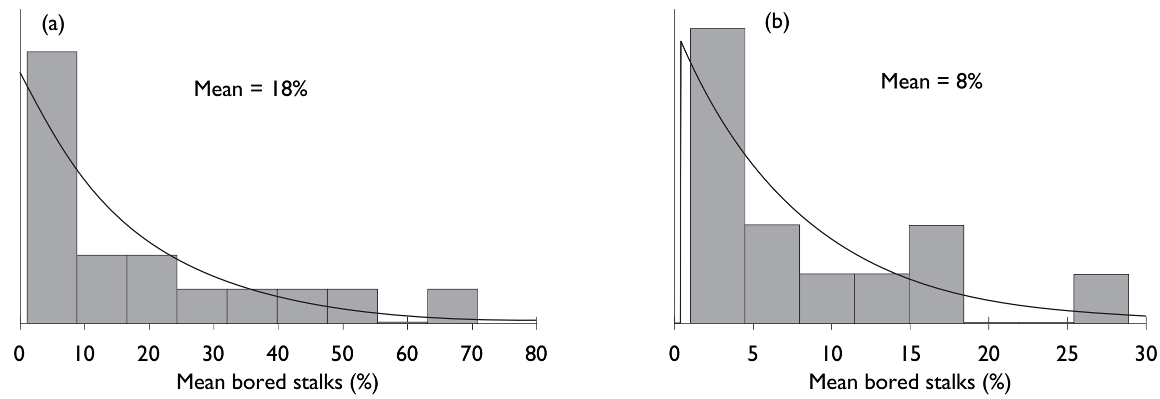
Developing a detailed model of moth behaviour is beyond the scope of the current analysis so, to model the level of attack, we explicitly treat it as a stochastic variable and use the past distribution of attack to derive a probability distribution for attack in the future.

Figure 3 indicated the history of attack (in terms of the percentage of bored stalks) from 1982 to 1998. We can use these data to estimate a probability distribution for the level of attack. Figure 7 gives a histogram and a fitted distribution using these historical data. Figure 7(a) shows the distribution using the full data-set, while Figure 7(b) shows the distribution excluding data from 1986 to 1989, which were exceptional years in that the very high levels of attack were the result of the extensive planting of the highly susceptible 'Cadmus' variety of cane. Since then, the cultural control methods at Ramu have sought to replant the estate with less-susceptible varieties. In deriving a probability distribution for use in the future, we consider it appropriate to exclude these highly susceptible years in estimating the probability distribution, as it is unlikely that highly susceptible varieties will be planted again. This decision has the effect of reducing the mean number of bored stalks from 18% to 8%.

The distribution that best fits the data (excluding the susceptible variety years) is an exponential one. Its simulated values are illustrated in

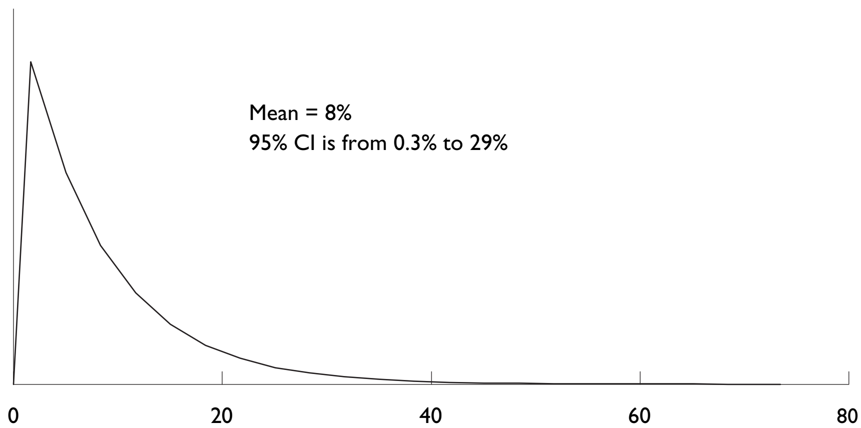
Figure 8.[5] This distribution indicates that there is a high probability of a low level of attack, with a declining probability of higher levels of attack. As this distribution is derived from the years in which elements of the IPM scheme were in place, but not including the use of the pheromone traps, we interpret this as providing a reasonable baseline against which to value the traps.

Figure 7. Historical frequency distribution of cane-borer attack at Ramu, Papua New Guinea



Data sources: CIE estimates based on data from Kuniata (1998) and Lloyd and Kuniata (2000).

Figure 8. Simulated probability of cane damage (percentage of stalks bored)



Data sources: CIE estimates based on data from Kuniata (1998) and Lloyd and Kuniata (2000).

[5] The density function for the exponential distribution is $f(x) = (e^{-x/\beta})/\beta$. The value of β for the fitted distribution is 7.9. In principle, the values of the distribution can extend to infinity, but for the simulation analysis we have truncated this. A number of other distributions also fit the data reasonably well, including the inverse Gauss and log logistic distributions. As these all have the same basic shape, using these alternative distributions does not change the results of the analysis.

The expected mean level of attack is 8% of bored stalks, with the 95% confidence interval being between 0.3% and 29%. Attacks of greater than 29% are possible, but very unlikely.

Relating attack to cane yield and sugar loss

The research by Kuniata (1998) indicates the relationship between cane damage, cane yield and sugar loss. Our ultimate objective is to estimate lost sugar production. This is itself composed of lost cane yield (i.e. less cane per hectare in production) and reduced sugar content (rendement) of the cane. Thus, we model sugar loss in two stages.

First, the loss in cane yield (tonnes/hectare) is a function of the proportion of bored stalks. Using data from Kuniata (1998) we estimate the following relationship:

Yield loss = 0.358 × *percentage of bored stalks*

The R-squared for this equation is 0.90, and the standard error on the estimated coefficient is 0.03 (implying a *t*-statistic of 11.86). We use this standard error to provide a confidence interval for the simulations of the expected loss from the cane borer.[6]

At the second stage, we relate the bored stalks to sugar yield. Again, using data from Kuniata (1998), we estimate the following relationship:

Sugar rendement = 9.38 – (0.026 × *percentage of bored stalks*)

The R-squared for this equation is 0.68. The standard error for the intercept term is 0.2 (a *t*-statistic of 45.7) and the standard error for the bored stalks effect is 0.007 (a *t*-statistic of 3.54). Again, these standard errors are used in the simulations presented below.[7]

These two relationships, along with the uncertainty associated with their parameters, provide a basis for estimating the expected loss in sugar production as a result of the cane borer attack.[8]

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[6] Kuniata (1998) finds that the best fit for yield loss is obtained by relating it to bored and rotting stalks. Here we use available data on bored stalks.

[7] Kuniata (1998) estimates sugar loss by relating the percentage of bored stalks to the proportion of the cane mass that is sucrose and then converting this to rendement using average relationships. Here we have directly related rendement to bored stalks, thus incorporating the relationship between the proportion of sucrose and rendement.

[8] Specifically, sugar loss = (cane yield loss) × (rendement without the borer) + (cane yield without the borer) × [(rendement without the borer) – (rendement with the borer)].

Relating damage to harvesting cost

Data from Kuniata (1998) suggest that harvesting costs increase as the level of bored stalks increases. Using these data, we assume that:

- attacks between 25 and 50% lead to an increase in harvest costs of \$0.017 per tonne
- attacks between 51 and 75% lead to an increase in harvest costs of \$0.116 per tonne
- any higher attack leads to an increase in harvest costs of \$0.20 per tonne.

Monitoring costs

As noted above, with the old monitoring technology, monitoring costs came to around \$2 per tonne. With the pheromone traps, costs are significantly reduced to \$0.55 per tonne.

Expected world sugar price

Using published world sugar prices, we note that there is a long-term tendency for real sugar prices to decline over time. We use a starting sugar price of \$190 per tonne (this is the landed price in PNG) and assume that the annual change in this price follows the distribution observed over the past 20 years. This distribution implies an average annual decline in the real world sugar price of 3.4%.[9]

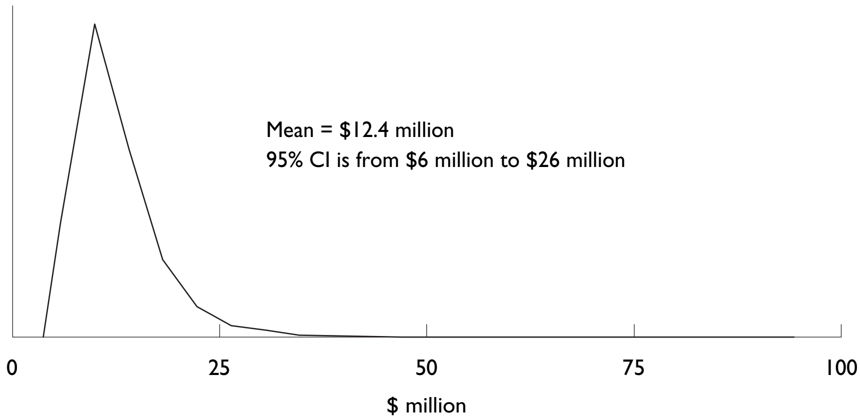
Expected loss over the next 30 years — without the traps

Figure 9 shows the estimated probability distribution for the present value (in 1995, over a 30-year horizon) of dollar losses as a result of the cane borer in the absence of the improved control using the pheromone traps. This probability distribution takes into account both the uncertain level of attack and the uncertain relationship between attack and damage, as well as uncertainty about the future price of sugar.

The mean expected cost is \$12.4 million, with the 95% confidence interval ranging from \$6 million to \$26 million. The distribution of these costs is highly skewed because of the skewed distribution of borer attack.

[9] A series for real sugar prices was taken from ABARE's Commodity Statistical Bulletin 2003 <www.abare.gov.au>. We estimate that the distribution of annual changes in the sugar price follows a logistic distribution.

Figure 9. Simulated present value of expected losses from cane borer at Ramu, Papua New Guinea



Data source: CIE estimates.

This loss can be put in perspective by considering that, over the next 30 years, assuming annual production of 50,000 tonnes and declining real sugar prices, the expected revenue from cane production has a present value of $123 million. The expected losses are therefore just under 10% of potential revenue.

As noted above, we interpret this probability distribution of costs as the baseline against which to value the pheromone traps, as this distribution includes the effect of other IPM measures, but not the effect of the traps.

The impact of the pheromone traps as a control measure

As noted above, the use of the pheromone traps appears to have enabled excellent control of the borer as well as providing a cheaper method of monitoring. To assess the value of this control, we use two scenarios, one in which the trap is assumed to have generated full control, and a second where it has generated only partial control.

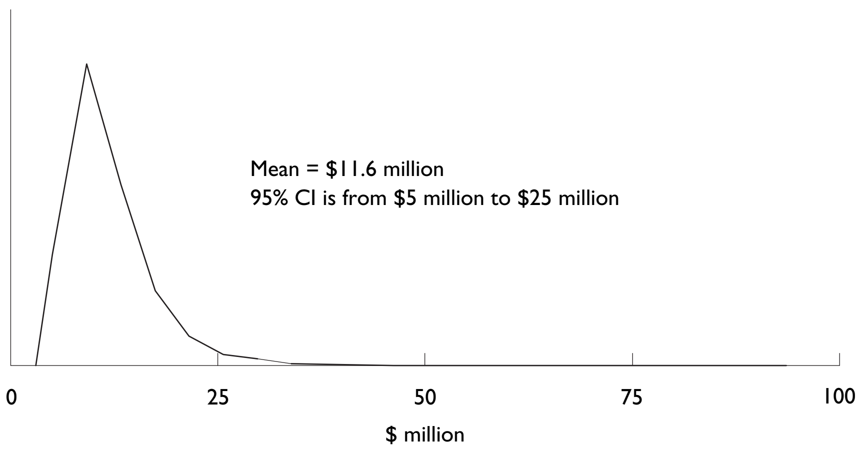
Scenario 1: traps lead to full control

Since its implementation, the trap technique has led to the virtual elimination of damage (L. Kuniata, pers. comm.). Assuming that this level of control continues, we can simulate the expected benefits from the traps. This expected benefit is simply equal to the cost of the borer under the baseline minus the cost under the control measure.

Figure 10 illustrates the expected benefits from the use of the pheromone trap control measure.

The mean of the present value of the net benefit (benefits of control less the cost of the project) is $11.6 million, with the 95% confidence interval ranging from $5 million to $25 million. As before, this distribution is highly skewed because of the skewed distribution of the borer attack.

Figure 10. Net present value of benefits assuming full control of cane borer at Ramu, Papua New Guinea



Data source: CIE estimates.

The costs of the research in 2005 dollars are $95,417. These benefits from the control measure imply a mean benefit–cost ratio of 122 to 1, with the confidence interval ranging from 55 to 1 to 266 to 1.

The benefits to date, under these assumptions, have a mean value of $2 million, with a confidence interval ranging from $800,000 to $6.5 million.

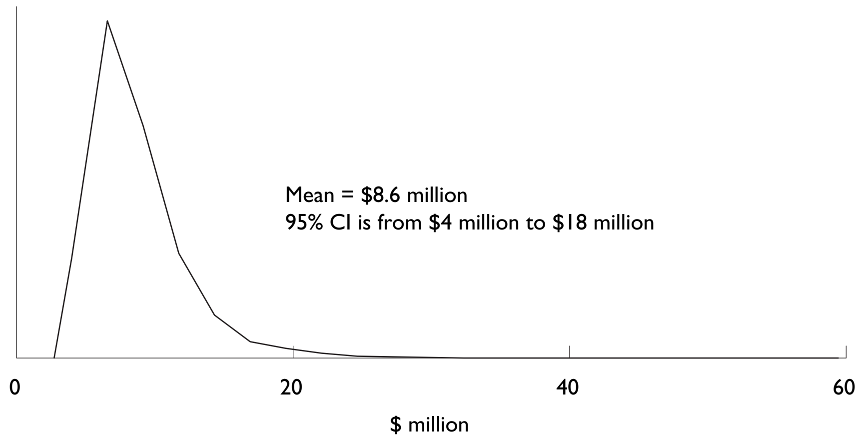
Scenario 2: Traps lead to partial control

It is possible that the apparent level of control in recent years is simply the result of a low level of attack, and that, with higher levels of attack, the control would not be as great. Here we assume that the level of control depends upon the level of attack, with the achievable level of control declining as the level of attack increases. In particular, we assume that:

- with attack less than 10%, 75% control can be achieved (that is, 75% of the damage that would otherwise have occurred is avoided)
- with attack of between 10 and 20%, 70% control can be achieved
- with attack of greater than 20%, the level of control linearly declines until it reaches 30% for an attack of 80%.

Figure 11 shows the distribution of the present value of the net benefits of the traps under these assumptions.

Figure 11. Distribution of net benefits assuming declining control of cane-borer moth at Ramu, Papua New Guinea



Data source: CIE estimates.

In this case, the mean benefit is $8.6 million, with a 95% confidence interval ranging from $4 million to $18 million.

These net benefits imply a mean benefit-cost ratio of 90 to 1, with a range from 46 to 1 to 187 to 1.

Under this scenario, the value of benefits to date has a mean of $2 million, and ranges from $750,000 to $4 million.

Distribution of benefits in PNG

As noted earlier, around one-quarter of the sugar produced at Ramu comes from out-growers. We would therefore expect around one-quarter of the benefits of the research to also accrue to these out-growers.

We do not have information about the distribution of income for the region around the sugar estate, so it is not possible to estimate whether the research has had any impact on poverty.

Benefits to Australia

The cane borer is a potential pest of sugarcane in Australia. Modelling as part of the ACIAR-funded project indicated that it could become established in cane-growing areas, if it arrived in Australia. Further, the borer is on the quarantine watch list.

However, the probability of the borer reaching Australia is likely very low, so that the use of the traps in PNG has probably not changed the chance of the borer getting into Australia, as the trap merely controls populations on the sugar estate, not in PNG as a whole.

Furthermore, the pheromone trap technique is not currently being used for quarantine monitoring.

Thus, while the traps could be useful as a monitoring measure if the borer came to Australia, the research itself has not led either to a reduction in the risk of the borer coming to Australia or to a reduction in quarantine monitoring costs (because it has not been adopted). At this stage, the benefits of the pheromone trap to Australia are thus very small.

5 Conclusion

The results of the benefit-cost analyses are summarised in Table 1.

Table 1. Summary of the results of the benefit–cost analysis of control of cane-borer moth at Ramu, Papua New Guinea using pheromone traps[a]

Measure		Assuming full control	Assuming partial and declining control
Present value of net benefits over 30 years	Mean	$11.6m	$8.6m
	Lower 95%	$5m	$4m
	Upper 95%	$25m	$18m
Present value of benefits to date	Mean	$2m	$2m
	Lower 95%	$0.8m	$0.75m
	Upper 95%	$6.5m	$4m
Benefit–cost ratio over 30 years	Mean	122:1	90:1
	Lower 95%	55:1	46:1
	Upper 95%	266:1	187:1
Benefit–cost ratio to date	Mean	20:1	20:1
	Lower 95%	8:1	8:1
	Upper 95%	61:1	42:1

[a] A real discount rate of 5% has been used for all PV calculations.
Source: CIE estimates.

While there is a large range in the benefit–cost ratios, they are generally all very high, indicating that the research has generated a significant payoff to the total funds employed.

The most reliable of these benefit–cost estimates are those for the benefits to date which (at the mean) generate a very healthy benefit–cost ratio of 20:1.

The benefits estimated over a 30-year time frame should be considered as more speculative. Ramu Sugar has been producing sugar for 23 years and over that time it has had highly varied fortunes with a range of pests. Evaluating one control method over a baseline that extends for 30 years (longer than Ramu's life so far) is clearly at risk of considerable error.

Nevertheless, the cane borer is a significant pest, and for relatively low expenditure the pheromone trap method appears to have significantly reduced the costs from the pest. A healthy benefit–cost ratio is not surprising in these circumstances.

As the research leading to the use of the trap was funded by CSIRO and Ramu Sugar as well as ACIAR, it may not be appropriate to attribute all the benefits to ACIAR. Discussion with the project leaders, however, indicates that there is a significant chance that the project would not have taken place without the ACIAR funding.

References

Kuniata, L. 1998. Borer damage and estimation of losses caused by *Sesamia grisescens* in sugarcane in Papua New Guinea. International Journal of Pest Management, 44(2), 93–98.

— 2002. Integration of insecticides in the management of *Sesamia grisescens* in sugarcane at Ramu, Papua New Guinea. Paper presented at the PNG First Plant Protection Workshop, Lae, October 2002.

— 2004. Outgrower participation in sugar production. Paper presented at the PNG Extension Summit, Lae, April 2004.

Lloyd, P. and Kuniata, L. 2000. The control of *Sesamia* at Ramu. Sugar Cane International, April, 10–17.

Mumford, J.D. and Norton, G.A. 1984. Economics of decision making in pest management. Annual Review of Entomology, 29, 157–174.

Peterson, R.K. and Hunt, T.E. 2003. The probabilistic economic injury level: incorporating uncertainty into pest management decision-making. Journal of Economic Entomology, 96, 536–542.

Sinden, J., Jones, R., Hester, S., Odom, D., Kalisch, C., James, R. and Cacho, O. 2004. The economic impact of weeds in Australia. Cooperative Research Centre for Australian Weed Management, Technical Series No. 8.

Whittle, C.P., Vickers, R.A., Kuniata, L.S., Bellas, T.E. and Rumbo, E.R. 1995. Identification of an attractant for caneborer *Sesamia grisescens* Walker. (Lepidoptera: Noctuidae). Journal of Chemical Ecology, 21, 1409–1420.

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